Design and Testing of a Small Inductive Pulsed Plasma Thruster

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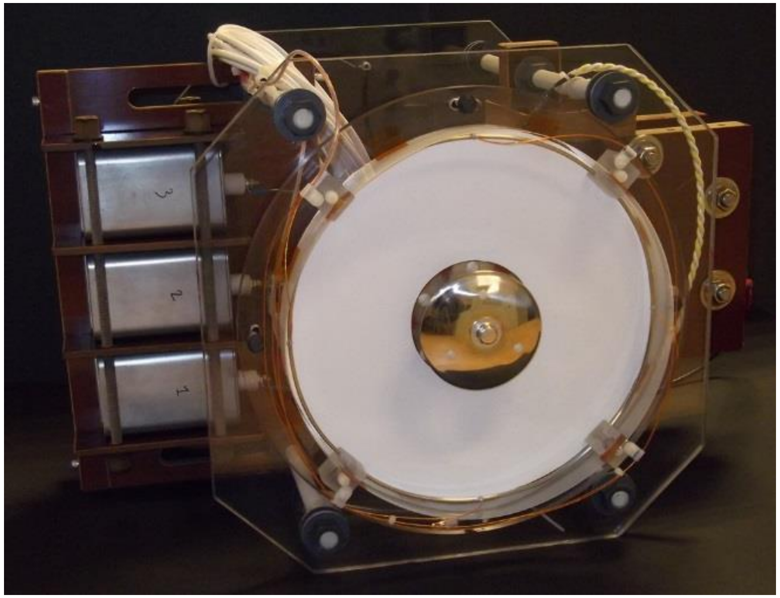
Introduction

- The Inductive Pulsed Plasma Thruster (IPPT) is an electromagnetic thruster that impulsively accelerates ionized propellant via the ***JxB*** body force.

- Potential advantages include:
    - Long operational life-time due to the absence of high-current electrodes
    - Ability to run on readily storable molecular propellants such as ammonia
    - I_{SP} can be independent of jet-power, P_{Jet}

- A small solid-state switched IPPT (*1-5 kWe) was* built with the goals of:
    - Demonstrating operation of an integrated solid-state switched IPPT.
    - Building a device that can be tested in cyclic mode on a thrust-stand.
    - Serve as a test-bed for solid state switching circuitry and pulsed gas valves.
    - The modular design of the device allows for a variety of configurations to be tested.



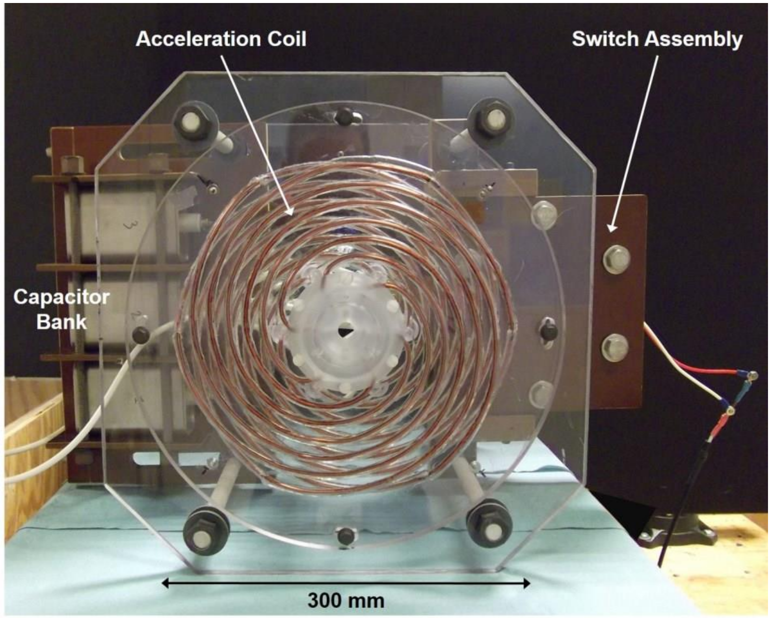
Design: Acceleration Coil

- The coil is wound on a Lexan coil form, and has six two-turn leads in parallel, clocked around the form at 60° intervals. Each turn is in the shape of an Archimedes-spiral ($r = a + b\theta$). The leads are No. 10 magnet wire, laid in CNC-machined grooves in a Lexan coil-form. Each lead is also insulated with Teflon heat-shrink tubing.

- Coil Dimensions:
  - o.d. = 270 mm
  - i.d. = 100 mm

- The coil is potted with Momentive RTV-560 high-voltage silicone insulation compound for additional insulation.

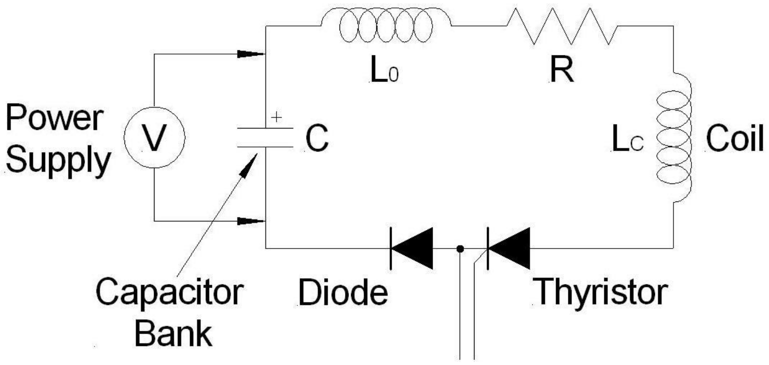
- The coil face was covered with an annular alumina-coated Mylar disk which provides insulation between the plasma and the coil and serves as a refractory plasma-facing wall.



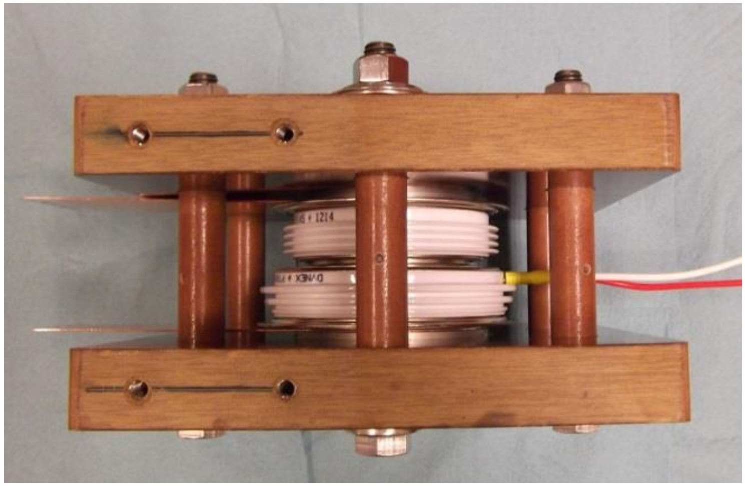
Partially assembled device with acceleration coil, capacitor bank, and switch assembly.

Design: Circuit and Switch Assembly

- Inductance: discussed later
- Capacitance: 9.88 μF
- Switch: Dynex PT85QWx45 pulse-power thyristor, 4.5 kV max. hold-off voltage, 30 kA surge current, max. *dI/dt* of 22 kA /μs
- Diode: Dynex DSF21545SV fast recovery diode, 20 kA max. current, 7 μs recovery time, 1.8 mC reverse recovery charge
- Thyristor and Diode are held in a clamp assembly and compressed with a force of 40 kN.



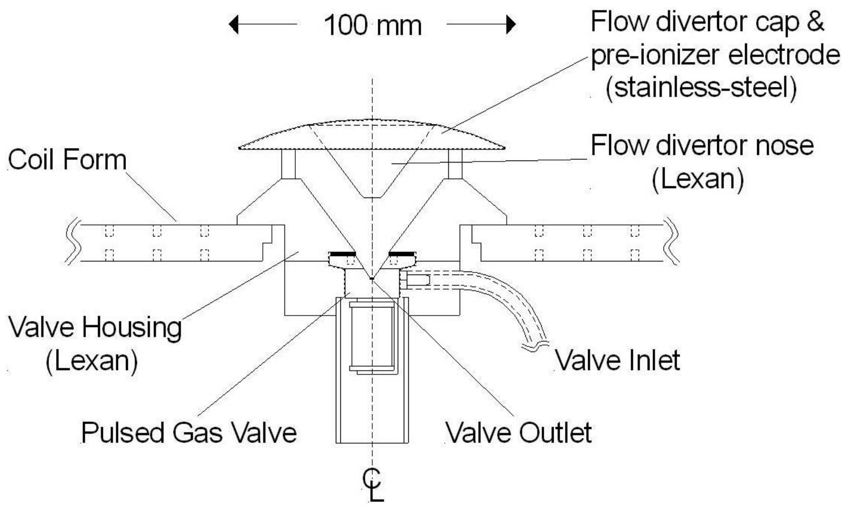
Acceleration coil circuit



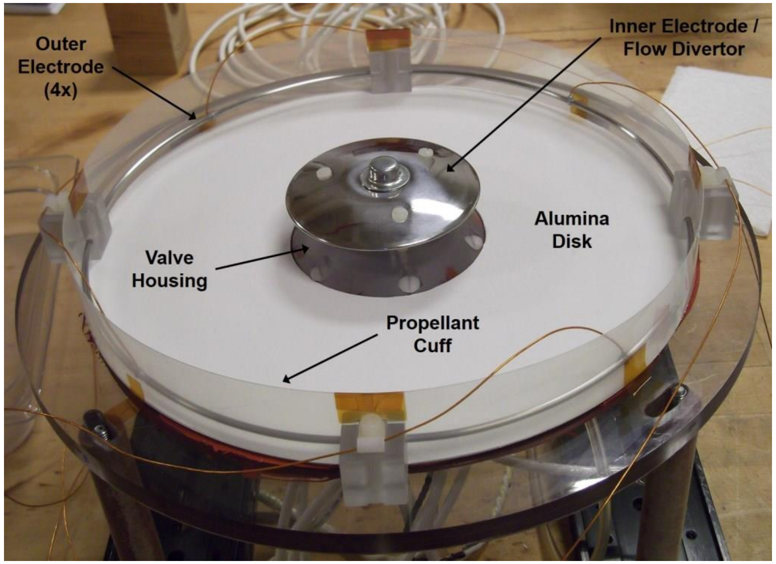
Switch assembly with thyristor and diode.

Design: Gas Valve and Pre-ionizer

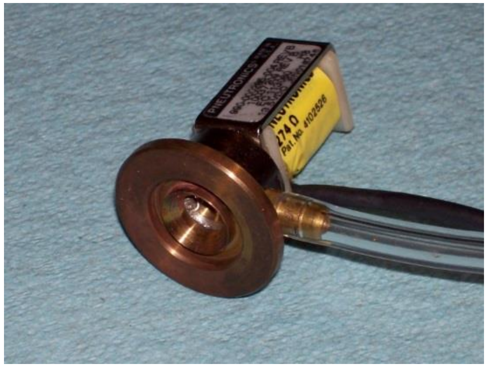
- Pulsed Gas-Valve: a modified solenoid fluid control valve
  - opening time of 300 μs.
  - 25-100 μg of propellant / pulse (in multi-pulse operation)
- Glow-discharge Pre-ionizer uses a 0.3 μF capacitor charged to ~ 4 kV



Plan view of gas-valve and housing



Coil-face with pre-ionizer



Pulsed gas-valve

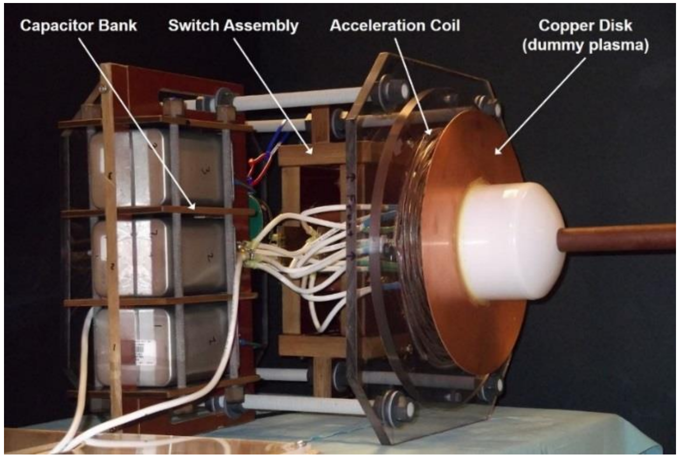
Bench-top Testing: Determination of Circuit Inductance

- Total circuit inductance was measured with the diode removed (ringing discharge)
- Coil inductance was calculated with QuickField v5.6
- Results from both were fit with the following function:

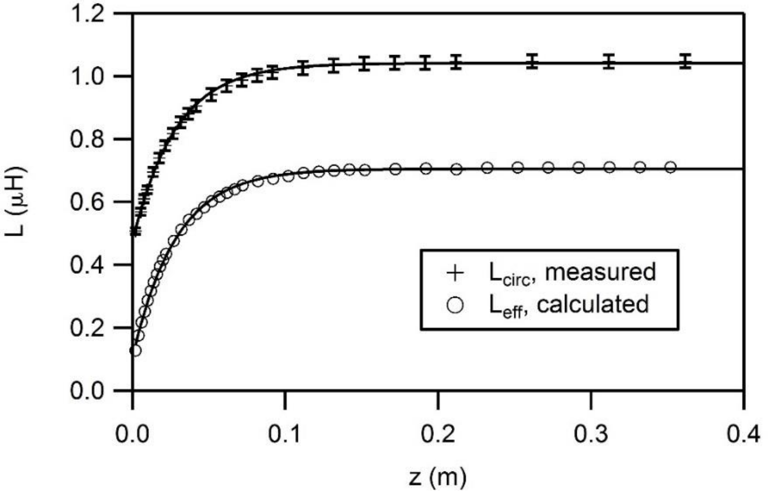
$$L(z) = L_\infty \left(1 - k_0^2 \, e^{-2(z/z_S)}\right)$$

	Quantity fit to:	
Fitting Parameter:	L_{eff}	L_{circ}
L_∞ **(nH)**	705 ± 3	1,041 ± 7
z_S **(mm)**	57 ± 1	57 ± 3
k_0	0.92 ± 0.01	NA
x^2 / n	0.4	0.1

- Calculated Coil Inductance: 705 nH
- Inferred External Inductance: 336 nH



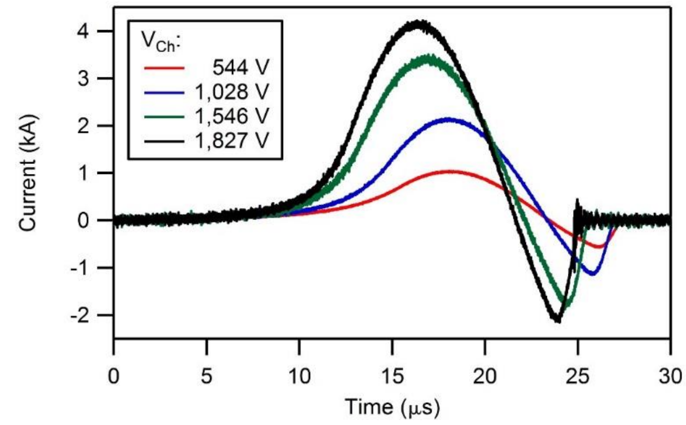
Experimental Setup



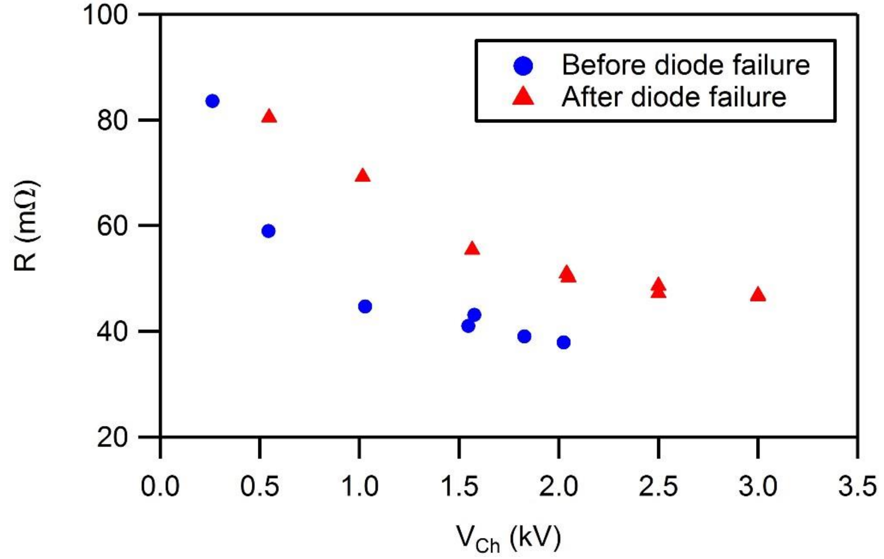
Inductance Measurement

Bench-top Testing: Component Testing at High Voltage

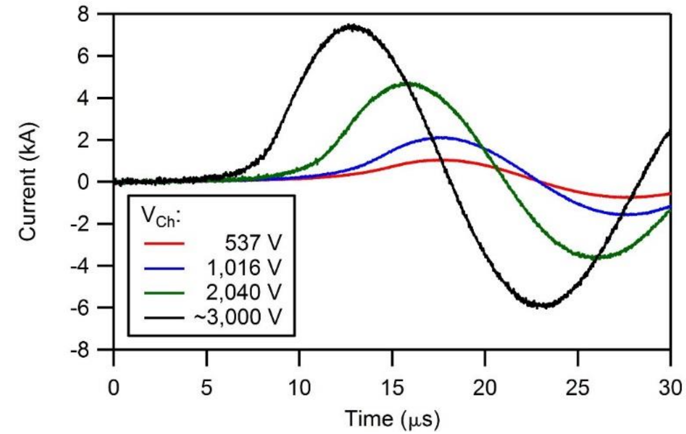
- Acceleration coil circuit tested up to 3 kV.
- Fast recovery diode failed at about 2 kV. at V_{Ch} ~ 1.8 kV, ΔQ = 4 mC > Q_{rr} = 1.8 mC
- Circuit Resistance decreases as V_{Ch} increases.



Before Diode Failure



Total Circuit Resistance



After Diode Failure

Vacuum Testing: Pre-ionizer

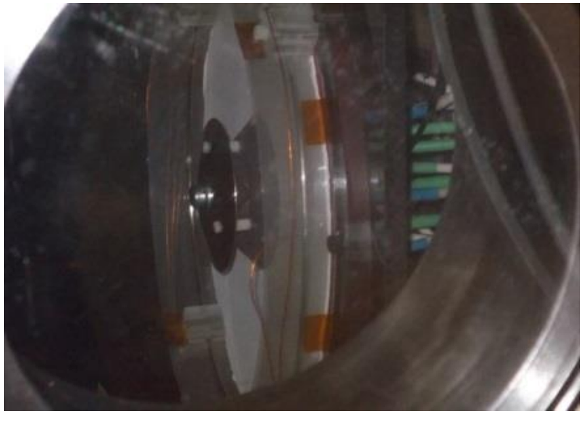
- Pre-ionizer capacitor with $C = 0.3\ \mu F$ charged to 4.1 kV: $E_{PI} = 2.5$ J
- Breakdown of the gas (argon) occurred when the valve is opened, allowing gas to bridge the electrodes
- The PI worked at cyclic rates of 1 Hz – higher rates are possible.

View of the thruster in the vacuum chamber

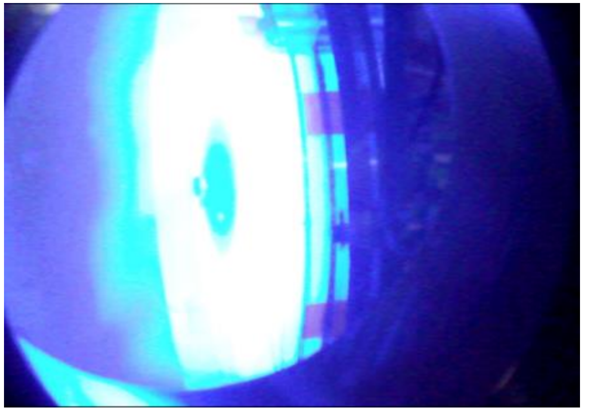
Pre-ionizer discharge

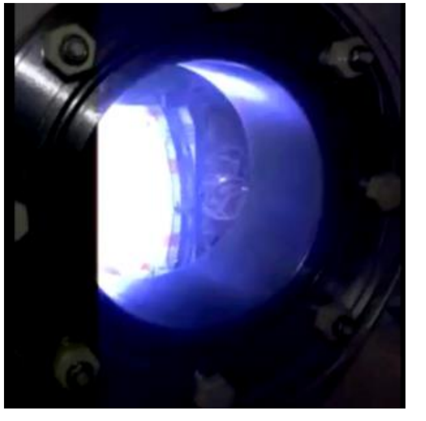
Vacuum Testing: Complete System

- Single-shot operation at V_{Ch} = 2 kV, with and without PI, Peak I_{Coil} = 4.05 kA
- A plasma formed even without the PI, i.e. just due to the *dI/dt* of the acceleration coil circuit itself
- The plasma formed with the PI appears to be brighter
- Repetitive operation demonstrated at cyclic-rate of 2 Hz
- A clog in the valve inlet was determined to have prevented operation at higher cyclic rates
- Insulation failures noticed after gas re-circulation in the chamber caused shorting.



View of the thruster in the vacuum chamber

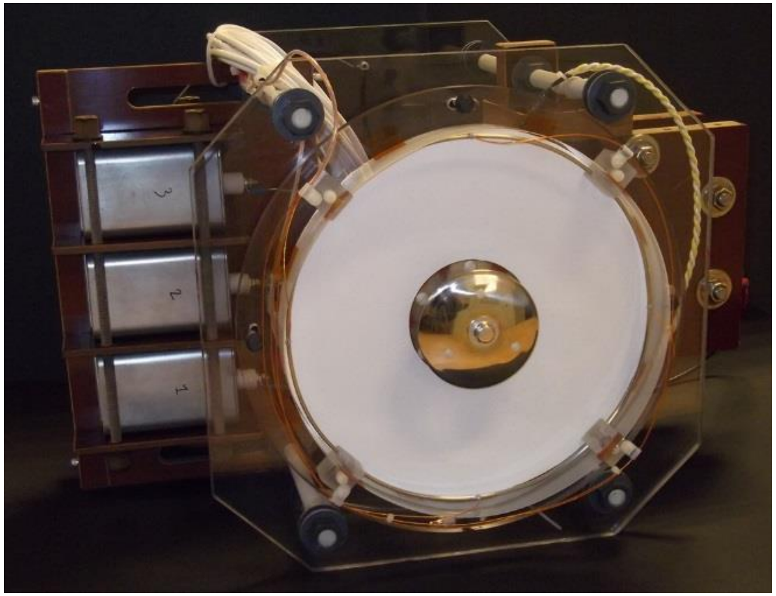




The IPPT thruster in operation

Conclusions and Future Work

- Cyclic operation of the IPPT has been demonstrated with all sub-systems functioning.
- Modifications are being made prior to next phase of testing:
  - Thyristor electrodes and terminations have been re-designed
  - HV insulation being re-done
  - Valve to be cleaned and rebuilt
- Subsequently, thruster to be installed in a larger chamber and thrust measurements made.



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